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## REVIEW OF ACOUSTO-ULTRASONIC NDE FOR COMPOSITES

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Acousto-ultrasonics utilizes simulated stress waves to detect and quantify defect states, damage conditions, and variations of mechanical properties in fiber reinforced composites. The term "acousto-ultrasonics" denotes a combination of aspects of acoustic emission methodology with ultrasonic materials characterization. The acousto-ultrasonic approach was developed to deal primarily with evaluation of the integrated effect of minor flaws and diffuse flaw populations of subcritical flaws in composite and bonded structures. These factors singly and collectively also influence acousto-ultrasonic measurements that, in turn, correlate with dynamic response and mechanical property variations. Since it was first introduced, the acousto-ultrasonic approach has been successfully applied to a variety of materials, including polymeric, metallic, and ceramic matrix composites; adhesively bonded materials; paper and wood products; cable and rope; and also human bone. Examples of applications and limitations of the approach are reviewed. Basic methods and guidelines are discussed. The underlying hypothesis and theory development needs are indicated.

## **THE ACOUSTO-ULTRASONIC APPROACH**

- **COMBINES SOME ASPECTS OF ACOUSTIC EMISSION METHODOLOGY WITH ULTRASONIC SIMULATION OF STRESS WAVES**
- **CONCERNED PRIMARILY WITH ASSESSMENT OF COLLECTIVE EFFECTS OF DISCRETE AND DIFFUSE FLAW POPULATIONS**
- **CONCERNED WITH VARIATIONS IN AND CORRELATIONS WITH:  
MATERIAL MORPHOLOGY, MECHANICAL PROPERTIES,  
INTERLAMINAR AND INTERFACIAL BOND STRENGTH,  
DEGRADATION FROM FATIGUE, IMPACT, ETC.**

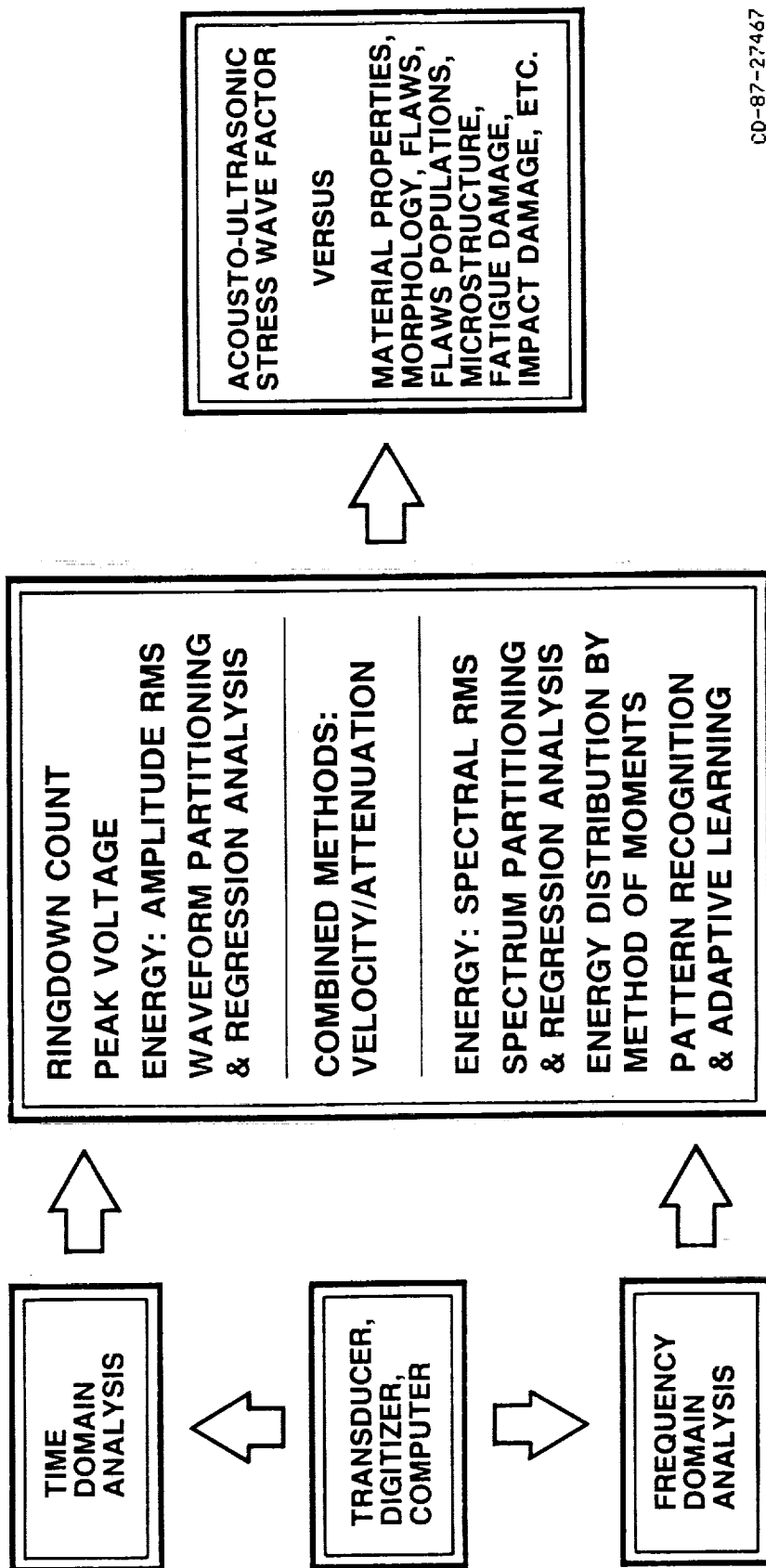
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## **CHALLENGES**

- ONLY ONE SIDE ACCESS AVAILABLE
- PULSE-ECHO APPROACH AMBIGUOUS
- LATERAL STRENGTH PROPERTIES
- NO EDGES OR EDGES INACCESSIBLE
- OBLIQUE INCIDENCE IMPRACTICAL
- BOND-LINE STRENGTH EVALUATION
- EFFECT OF FLAWS AMBIGUOUS

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# QUANTITATIVE SIGNAL PROCESSING FOR ACOUSTO-ULTRASONICS



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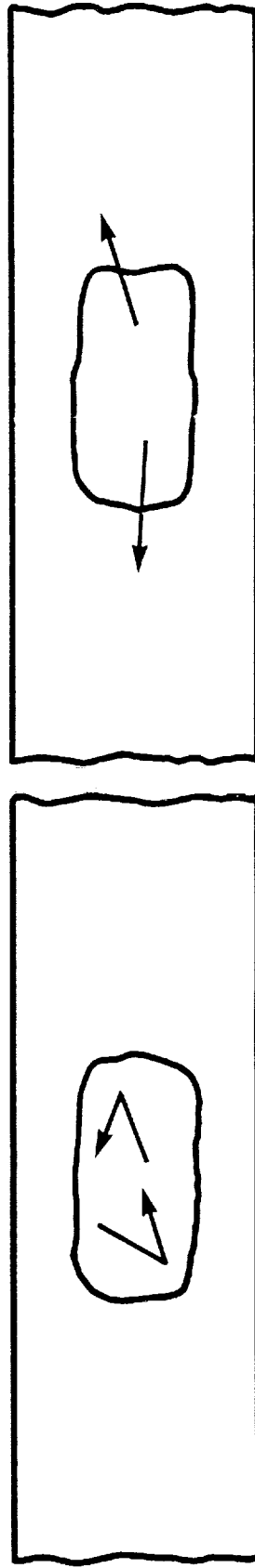
## **THE STRESS WAVE FACTOR**

- **STRESS WAVE FACTOR (SWF) QUANTIFIES ACOUSTO-ULTRASONIC SIGNALS**
- **DOMINANT EFFECT MEASURED BY (SWF) IS ULTRASONIC ATTENUATION**
- **HIGHER VALUES OF (SWF) GENERALLY CORRESPOND TO LOWER ATTENUATION**

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## WORKING HYPOTHESES

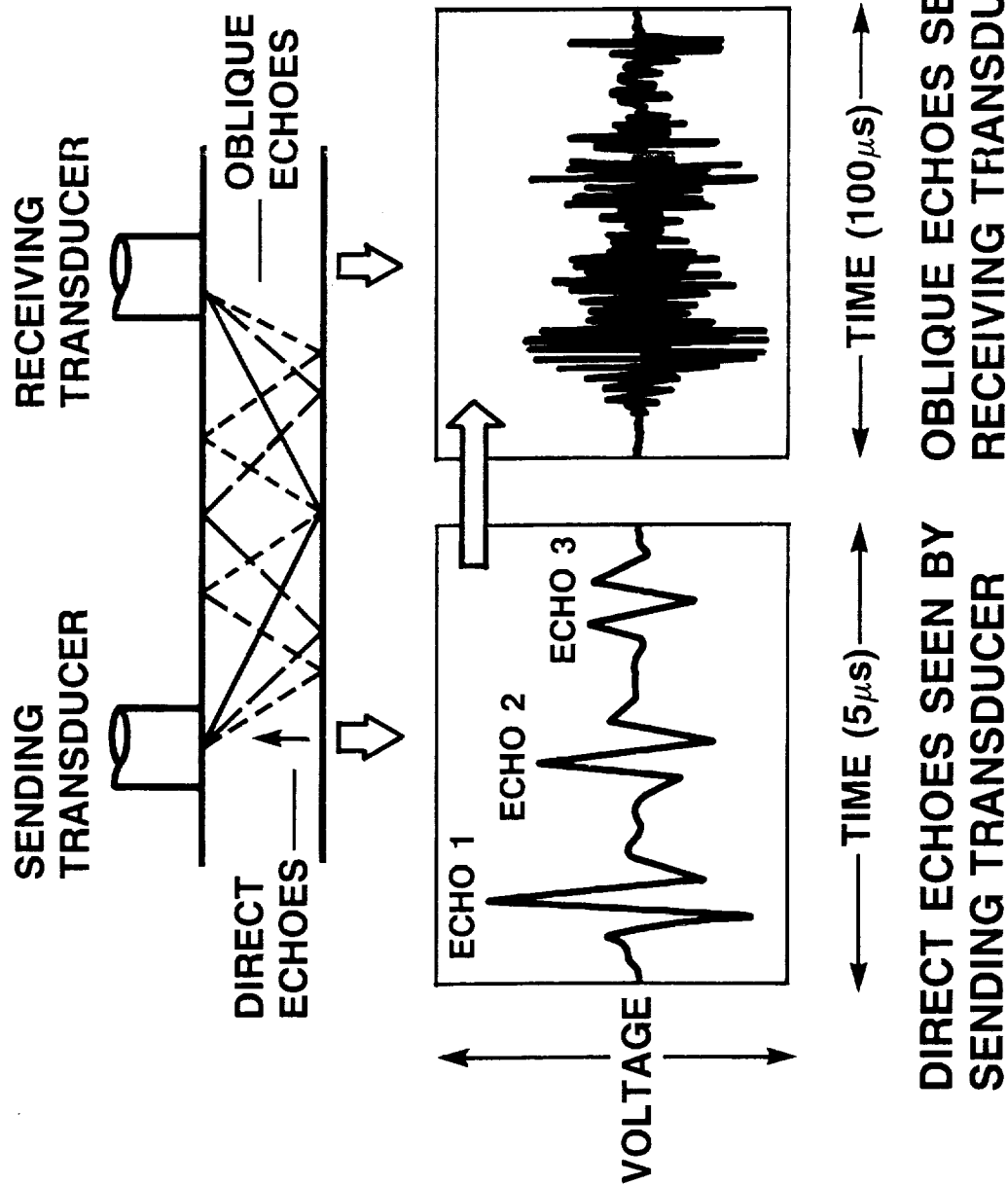
- (SWF) MEASURES RELATIVE EFFICIENCY OF STRESS WAVE ENERGY FLOW
- BETTER ENERGY FLOW MEANS BETTER DYNAMIC STRAIN DISTRIBUTION
- PROMPT, EFFICIENT FLOW OF STRESS WAVE ENERGY AWAY FROM CRACK NUCLEATION SITES IS NEEDED TO AVOID CATASTROPIC FRACTURE WHEN THE ENERGY CANNOT BE ABSORBED LOCALLY



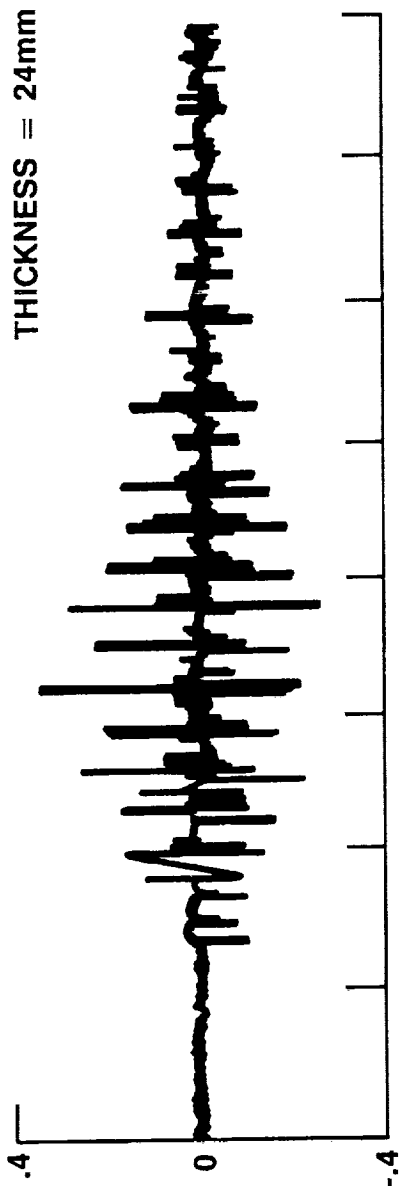
CRACK NUCLEATION ENERGY CONFINED      CRACK NUCLEATION ENERGY DISSIPATED

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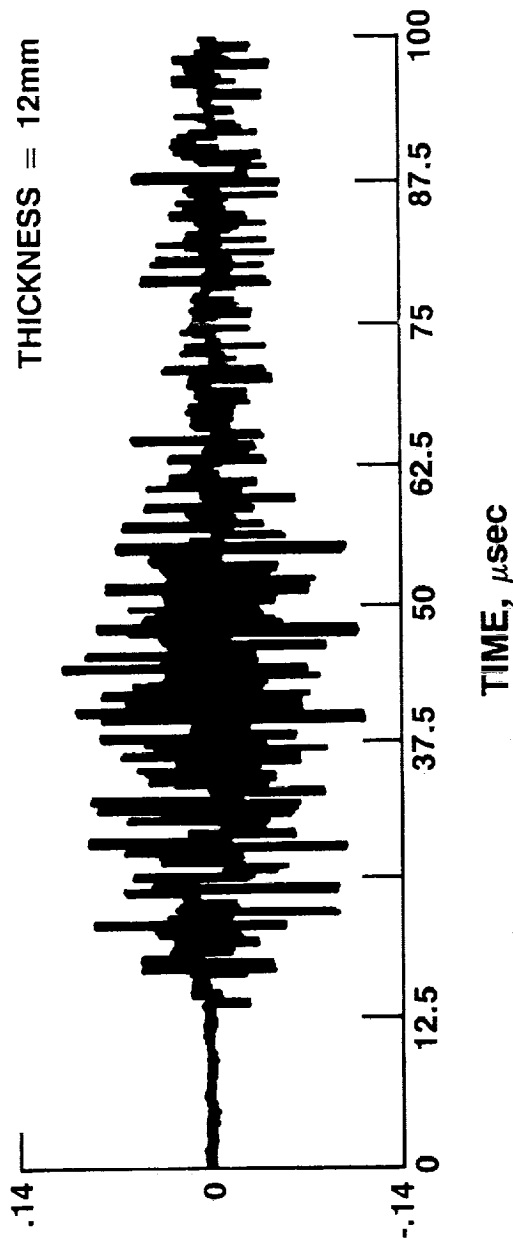
# REPRESENTATIVE ECHO SYSTEMS FOR BASIC ACOUSTO-ULTRASONIC CONFIGURATION



# ACOUSTO-ULTRASONIC WAVEFORMS FROM ALUMINUM PLATES WITH TWO DIFFERENT THICKNESS



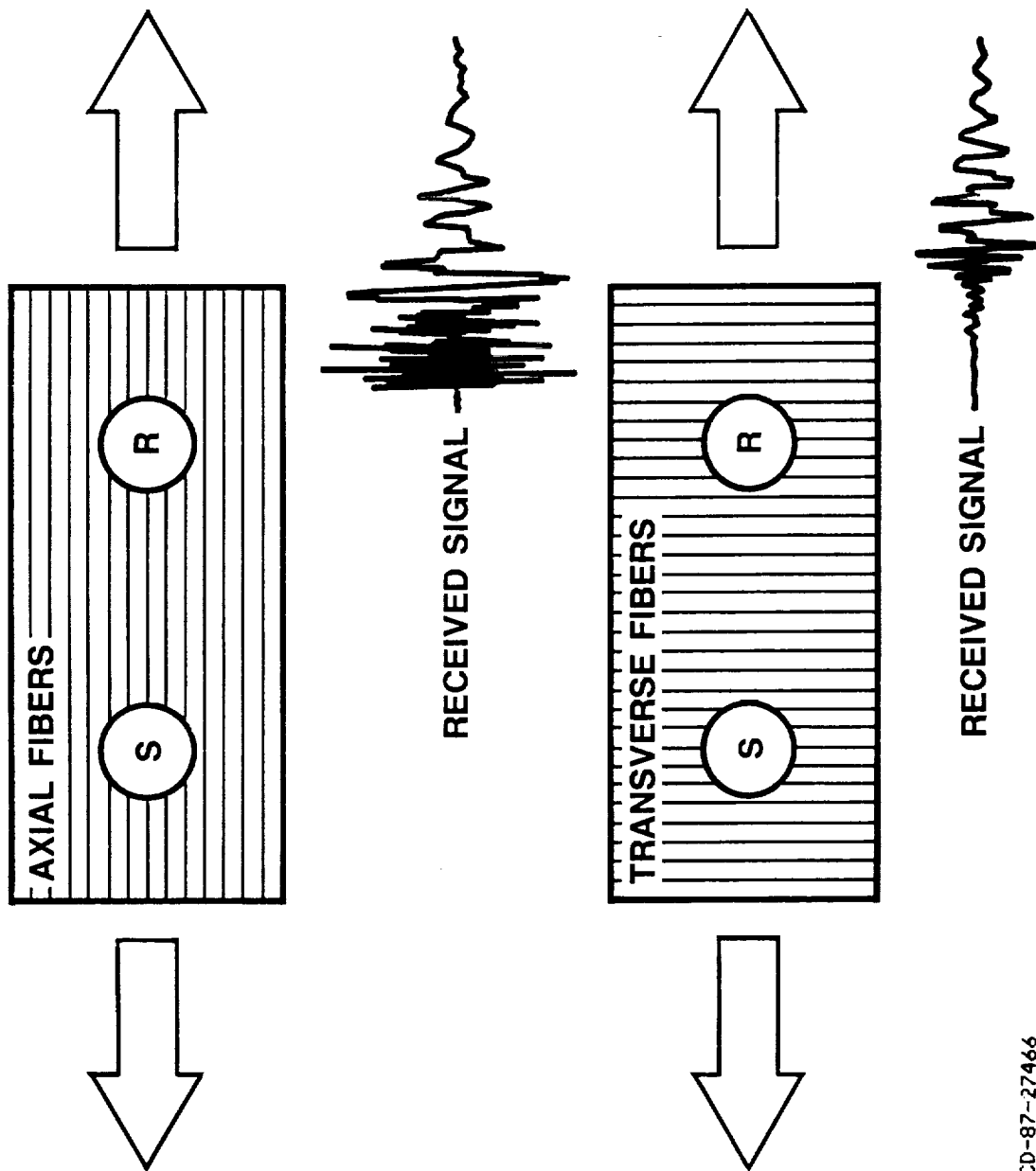
RECEIVED  
SIGNAL,  
VOLTS



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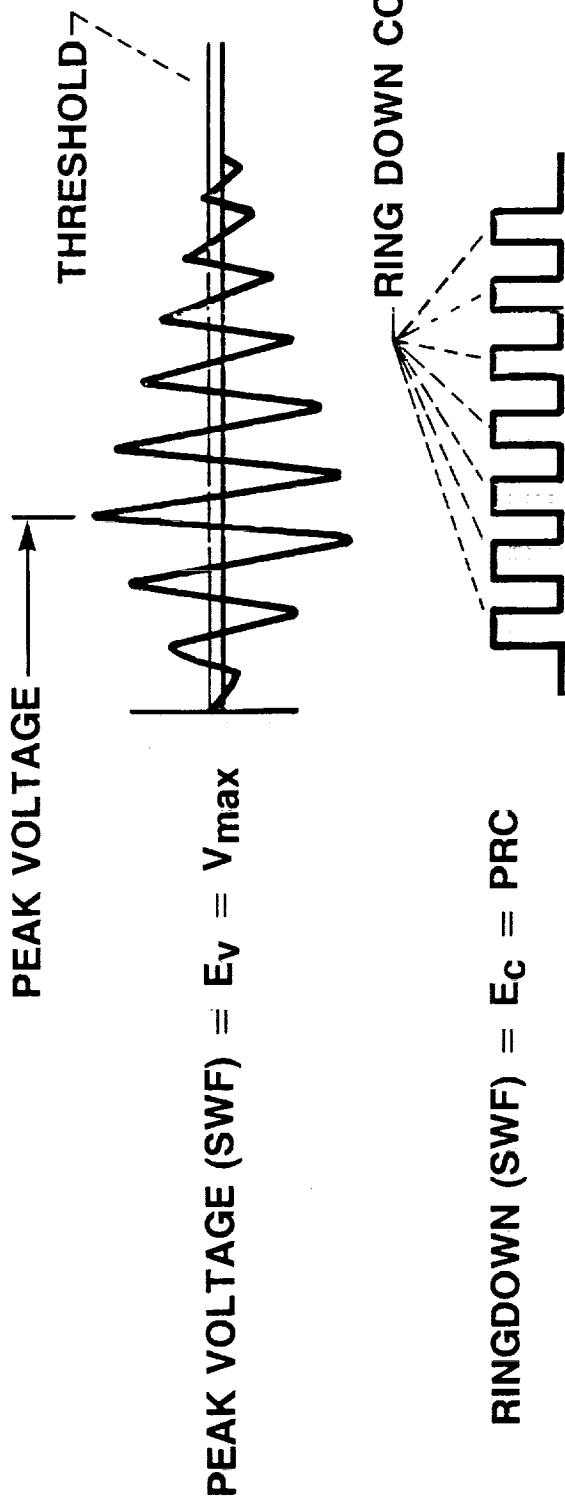


# VARIATION OF ACOUSTO-ULTRASONIC SIGNAL RELATIVE TO FIBER DIRECTION IN UNDIRECTIONAL COMPOSITE LAMINATE



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# QUANTITATIVE SIGNAL PROCESSING FOR STRESS WAVE FACTOR (SWF) USING ACOUSTIC EMISSION METHODOLOGY



P = PULSE RATE, R = RESET TIME, C = RINGDOWN COUNT

# QUANTITATIVE SIGNAL PROCESSING FOR STRESS WAVE FACTOR (SWF) BY PARTITIONING OF ROOT MEAN SQUARE (rms) ENERGY

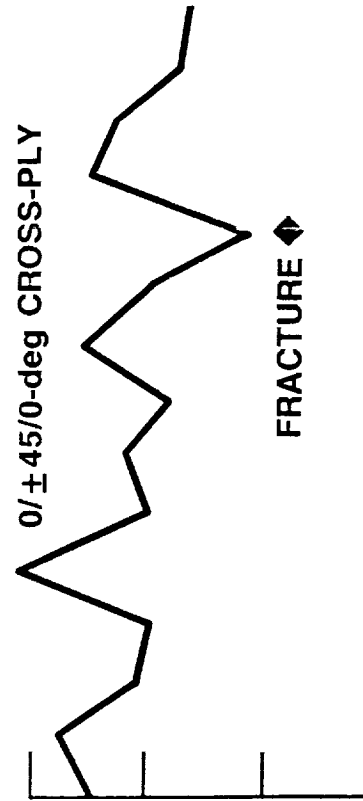
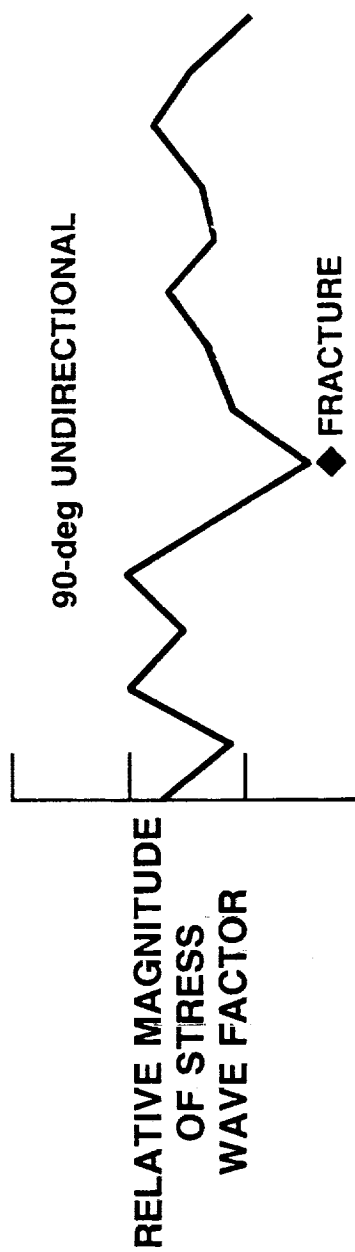
$$\text{TIME DOMAIN (SWF)} = E_t = (V_{rms})^2 = \frac{1}{T} \int_{t_1}^{t_2} v^2 dt$$

$$\text{FREQUENCY DOMAIN (SWF)} = E_f = (S_{rms})^2 = \frac{1}{F} \int_{f_1}^{f_2} s^2 df$$

$$T = t_2 - t_1 \text{ AND } F = f_2 - f_1$$

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# CORRELATION OF STRESS WAVE FACTOR WITH FAILURE SITES IN GRAPHITE/EPOXY TENSILE SPECIMENS

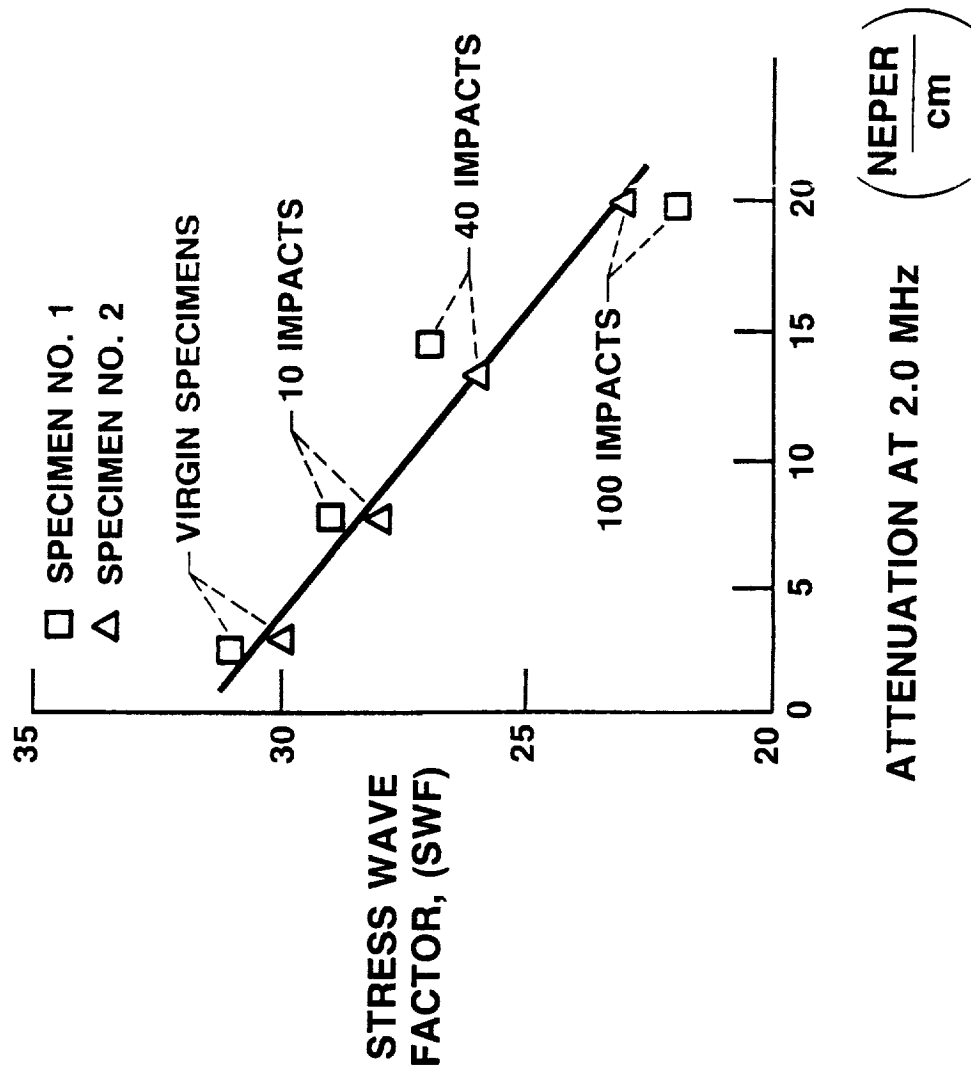


SCALE DISTANCE ALONG SPECIMEN

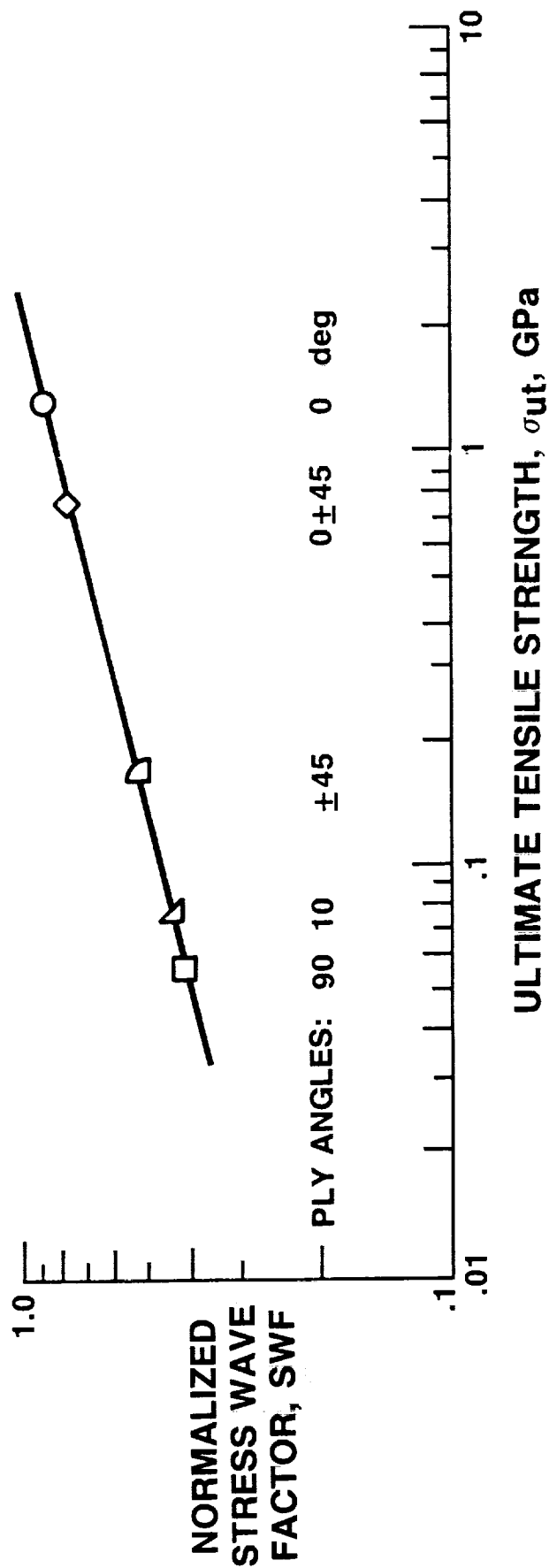
TAB	TEST SECTION	TAB
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# STRESS WAVE FACTOR (SWF) VERSUS THROUGH-TRANSMISSION ULTRASONIC ATTENUATION AT IMPACT SITE OF 10-PLY UNIDIRECTIONAL GRAPHITE/EPOXY COMPOSITE LAMINATE SPECIMENS

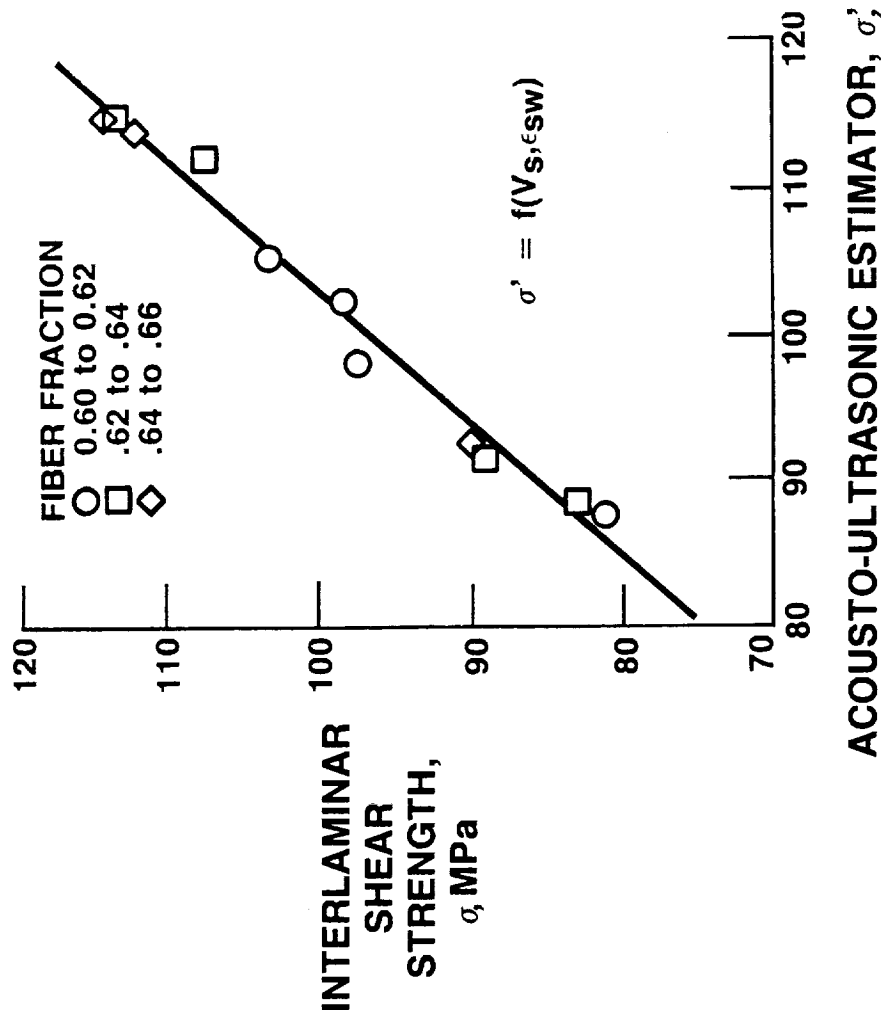


# ACOUSTO-ULTRASONIC STRESS WAVE FACTOR AS CO-FUNCTION OF ULTIMATED TENSILE STRENGTH AND FIBER/PLY ANGLE IN COMPOSITE LAMINATE

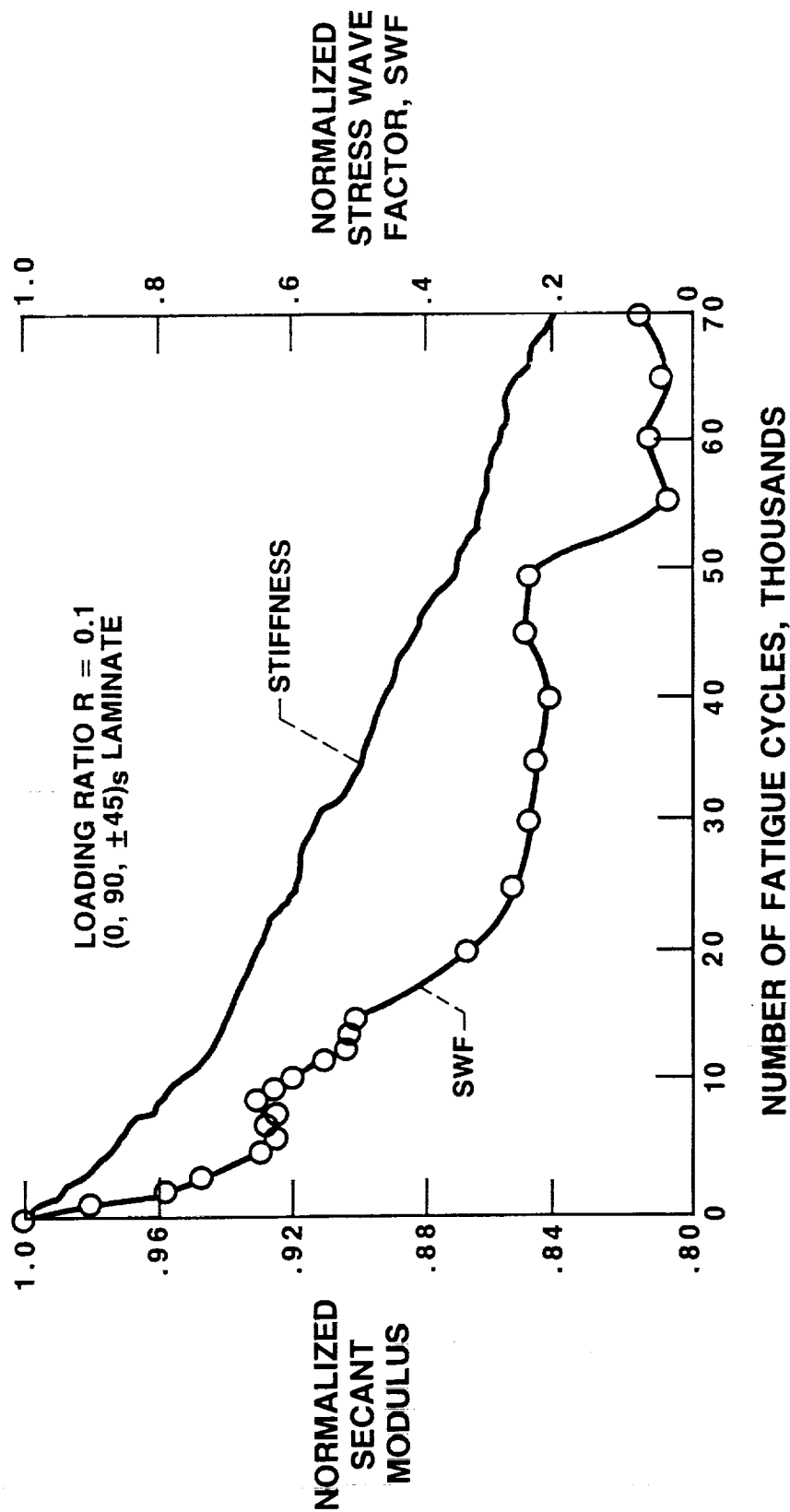


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# CORRELATION OF INTERLAMINAR SHEAR STRENGTH WITH THE ACOUSTO-ULTRASONIC ESTIMATOR FOR GRAPHITE/POLYIMIDE FIBER COMPOSITE LAMINATE



# COVARIATION OF STRESS WAVE FACTOR AND LONGITUDINAL SECANT MODULUS WITH FATIGUE DAMAGE IN GRAPHITE/EPOXY FIBER COMPOSITE LAMINATE



DIFFERENCE IN SLOPES IS BECAUSE SECANT MODULUS  
IS FOR FULL GAGE LENGTH WHILE (SWF) IS FOR LOCAL  
ZONE ON TEST SPECIMEN

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## **CONCLUSIONS**

- **UNDERLYING (SWF) HYPOTHESIS APPEARS TO BE CONFIRMED**
- **CAPABILITY FOR PREDICTING POTENTIAL FAILURE SITES**
- **MEASUREMENT OF DEGRADATION DUE TO IMPACT, FATIGUE**
- **CORRELATIONS WITH INTERLAMINAR, ULTIMATE STRENGTH**

